Art. VII.—*Notes on a Chronographic Apparatus, with Huyghen's Parabolic Pendulum.*

By R. L. J. Ellery, Esq.

[Read 25th September, 1876.]

About three years ago, at a meeting of the physical section of this Society, I gave a brief *résumé* of the various methods that had been tried for obtaining *uniform rotation*, more especially for astronomical and physical instruments; and I pointed out that as the desired result had been only approached, but in no case obtained, it was a subject worthy of the consideration of the section, and it consequently formed the matter for discussion at a subsequent meeting.

It may be as well to state here that all the most successful attempts to solve this mechanical problem involved the use of the fly, the rotating or conical pendulum, and reciprocating pendulum, either alone or in combination.

The governor of a steam-engine is an apparatus the object of which is to secure uniform rotation, and is usually simply a double conical pendulum; but we know that as the time of rotation of a conical pendulum varies very considerably with the distance the pendulum's bobs are from the axis of rotation, this arrangement alone cannot possibly secure the desired effect, while it usually serves to govern the supply of steam sufficiently to obtain enough uniformity of motion for the practical purposes of a steam-engine. It is, however to the case of the astronomical or physical chronograph, where absolute uniformity is the most to be desired, and indeed a necessity, that I shall have principally to refer; and I shall therefore limit my observations to this higher requirement.

Although the conical pendulum is sometimes used for governing chronographic instruments, it does not, for the reason stated above, afford good results; if however it were possible to secure a constant driving force and resistance, and therefore a constant arc, it would no doubt be perfect; but we know it is impossible to attain these conditions.

In my experiments I have found that a simple free conical pendulum, with a "bob" very heavy in proportion to its length, gives results very near to uniformity if the train be moderately good.

In order to secure a nearly uniform arc with the conical pendulum many devices have been adopted, most of which depend upon having an excess of driving power and the variable excess used up by friction which is brought into play by the pendulum itself as its arc increases beyond a certain limit; but as giving the pendulum any work of this kind to do leaves it no longer free, it becomes simply a "make shift," and can only approach uniformity within larger limits than should be nowadays admissible.

The most successful "governors" of this class hitherto constructed appear to be those where the motion of the mechanism is rendered approximately uniform by the fly, and then finally controlled by a reciprocating pendulum, as in "Bond's Spring Governor," or "Cook's Governor," where a driven train of wheels is governed by a fly, but pulled up every half-second by a vibrating pendulum; the pulling-up being made as gradual as possible by means of a light spring or weight inserted between the fly and the pendulum, allowing the former to continue revolving with increasing resistance until the latter allows its wheel to escape and so free the fly. These are practically the best forms of chronographic governors in general use, but as there is a periodic error of half a second inherent in them they are really imperfect.

There is a form of governor which almost secures uniform rotation, namely the vibrating spring; and the more rapid the vibrations are the more nearly perfect is the result. Some chronographs have been made on this plan, and are known as Hipps' Chronographs. They consist of a driven train and registering barrel, governed by a flat, straight steel spring, whose end just touches the ends of the teeth of a wheel, but which by a little rotatory force in the wheel can be pushed or bent so as to allow the teeth to pass it one after another; the rate at which the wheel rotates being governed by the natural time of vibration of the spring, which is constant at the same temperature, and the rotation of the train is therefore uniform, except for the small periodic error of which the time of the spring's vibration is the measure. In practice, however, I believe the escape-wheel sometimes slips or runs. The noise, too, caused by the vibration of the spring is almost intolerable, and one of the American observers at the late transit of Venus told me he had to dig a big hole in the ground, place the apparatus in it, and cover it over before he could bear the din.

Siemens proposed a "governor" where the control was afforded by the varying friction of a fluid in a rotating parabolic cup. This, although theoretically excellent, does not appear to have given satisfactory results in practice.

After this brief glance at the methods already adopted or proposed for obtaining uniform rotation, I will now return to the more special subjects of these notes.

At the subsequent meeting of our Section A the question of uniform rotation was discussed, and Mr. Kernot suggested Huyghens' Parabolic Pendulum as a governor, and submitted a plan for its construction. Now, Huyghens' pendulum was invented 200 years ago, and is theoretically a perfect governor; but with the exception of a rough imitation of the principle in a steam-engine governor I could not find that it had ever been used or even tried. I determined, however, to adopt Mr. Kernot's suggestion, and try this governor. At first the results gave me no encouragement, and I almost determined to give it up, more especially as I imagined that there must be some almost insuperable practical difficulty in the way to account for so old and theoretically perfect a "governor" never having been adopted. However, by a little perseverance and alteration of form of pendulum, I arrived at better results, and eventually succeeded in getting a pendulum constructed which is almost practically perfect, and the performance of which has withstood far more trying tests than it would be subjected to in practice. Huyghens' Parabolic Pendulum therefore has in my hands given the closest approximation to uniform rotation ever yet, I believe, obtained; and that with a mechanism so simple and easily constructed as to put all the more elaborate but less effective forms in the shade.

While in England last year I read a paper to the Royal Astronomical Society on "Some Experiments with Huyghens' Parabolic Pendulum," but was not able to show one in operation. I can now do so, and that is my excuse for bringing it under your notice this evening. In the paper referred to I gave the principle of construction I had adopted, and the conditions I had found necessary to secure success. It is nevertheless, I think, desirable to give a brief description of the pendulum in this place, more especially as I have the whole apparatus in working order before you.

This chronograph apparatus is not very different from the ordinary forms, and is styled a "barrel chronograph," because the registration takes place on paper covering a barrel which, by reason of the perfect governance of the pendulum, revolves precisely once in a minute, while a syphon pen, actuated by an electro magnet, makes a mark on the paper every second, as the current from a galvanic battery is transmitted by a miniature key operated by the mechanism of a clock or chronometer.

The syphon pen really marks a continuous line, which is interrupted every second by a small "offset" or "tooth" and constitues the "mark;" and an "offset" is left out once in every complete revolution of the barrel, every minute in fact, at the same time the little carriage carrying the pen and magnet is continually progressing in the direction of the length of the barrel, at the rate of about one-tenth of an inch per minute, converting the continuous line into a spiral on the cylinder.

I described a chronograph to this Society about 13 or 14 years ago, and as the principle in this is much the same as in the one then described, and very similar to other barrel chronographs—such as Bond's, Hipps', &c.—it will not be necessary to refer to any details except the pendulum, which in this case is the only new or peculiar arrangement.

"Let A A *(Fig.* 1.) be a vertical axis of rotation, which can be driven by clockwork acting at the top or bottom of the axis; from this axis a pendulum (P) is suspended in such a way that when it hangs vertically the string (S) lies wrapped over a curved surface, which forms part and parcel of the vertical axis. This curve is the evolute of a parabola, whose distance from vertex to focus is half the length of the required pendulum (when vertical). Now, let the axis revolve, and the pendulum will fly out from its vertical position, more or less, according to its weight and the driving power; the arc described by the pendulum, as it increases its distance from the vertical, will be a parabola, by reason of the string gradually unwrapping from the evolute (E). Now, from the properties of the parabola, it follows that the vertical distance between the centre of rotation of the pendulum (P) and the intersection of the string (S) with the axis of rotation of the pendulum will remain constant; and therefore that the length of the pendulum remains constant at whatever arc it may rotate.

"To practically secure these conditions it is necessary, first that the evolute shall be properly and precisely made; and secondly, that it shall be so adjusted that the axis of the evolute and involute shall be coincident with the axis of rotation.

"The pendulums I had constructed are *half-seconds,* that is, rotating once in a second. They are suspended in a hard gun-metal frame (Fig. 2), pivoted at the top and bottom, the lower pivot resting on an end jewel, the upper pivot supported by a strong cast-iron bracket, and it is driven by a contrate wheel in the clock train, engaging into a pinion in the lower end of a frame. The frame is open (as shown in *Fig.* 1) to allow of the middle part of the axis of rotation being clear for the evolute and the pendulum string or rod. The evolute is fixed at M, and is capable of adjustment at right-angles to the axis of rotation by a screw (Q), the proper position of the curve in the other direction being practically secured by careful workmanship, more especially in the construction of the evolute itself.

"The pendulum consists of a spherical bob, weighing about two and a half pounds, on a steel rod about one-tenth of an inch thick, and suspended by a long and *exceedingly thin* steel spring secured to the top of the evolute at N.

"The regulation of the length of the pendulum is done in the ordinary way with a nut at the bottom of the steel rod.

"The governor thus made with ordinary care and workmanship is by far the best of any of which I have had experience, and has furnished results better, I believe, than any others used with chronographs; at the same time it is simple and inexpensive."*

It is very necessary that the suspension-spring should be of the thinnest steel possible, and I have found what is known as French clock pendulum-spring to answer very well. The adjustment of the evolute is a somewhat tedious operation, but can be accomplished with great precision with care. To get its proper position, if the time of rotation increases with an increase of arc—in other words, if it revolves slower for increase of arc—the axis of the evolute is beyond the axis of rotation (reckoning from the pendulum side of the axis), and it is too near if it revolves more rapidly for increase of arc. Of course for each alteration of the position of the evolute a considerable alteration of the length of the pendulum becomes necessary, and this somewhat complicates the adjustment; but with a barrel chronograph this is easily overcome by alternately increasing and diminishing the arc of the pendulum by adding to and subtracting from the driving weight.

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* Extract from Monthly Notices of the Royal Astronomical Society; page 72, Vol. XXXVI.